THE "SHOT-HOLE" FUNGI OF STONE-FRUIT TREES IN AUSTRALIA.

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There are a number of fungi, growing principally upon leaves, which attack the tissues in spots and cause these spots to dry up and wither, until finally they drop out and leave more or less round holes in the leaf as if it were riddled by shot. The spores of such fungi evidently start from a definite centre and produce hyphæ radiating all round till they have exhausted or destroyed the tissues within a certain radius, and the dried-up spots thus deprived of their substance soon lose organic connection with the surrounding tissues. The diseased tissue shrinks and gradually becomes detached, so that in many cases the line of demarcation between the sound and diseased portions is so sharply marked as to make a complete raised ring round the spot. A healing process takes place by the formation of a kind of callus which prevents the further disruption of the leaf. Fresh spores are being constantly produced by the fungus and conveyed to new centres of infection, so that the leaf soon becomes riddled with holes.

From the fungus point of view, the object of the falling away of circumscribed portions of the leaf is obvious. They form a convenient substratum for the production and wintering of the spores, until favourable conditions arise for their further development. But that the formation of the callus in the leaves of stone-fruit trees is an effort of the tree to get rid of the parasite is evident from the behaviour of such leaves when plucked from the tree and kept moist for several days. The mycelium of the fungus soon begins to spread from the spots to the other portions

of the leaf, producing large indefinite patches which bear innumerable fructifications of the fungus. Here there is no formation of callus, and this following upon the stoppage of the vital activities of the leaf, leads to the conclusion that the callus-formation or separation layer is a special character possessed in particular by the living leaves of the stone-fruit trees and designed to minimise or localise the attacks of the fungus.

The bearing of this on the treatment of the disease is obvious. It has been recommended to give the first spraying to Apricot trees badly affected with shot-hole as soon as the leaves turn colour, because when they fall they deposit the spores in the soil. But before this happens innumerable minute round portions of the leaves have already fallen to the ground, bearing with them the seeds of the disease, which will be ready to germinate at least when the buds burst.

Fungi producing "Shot-hole" generally.

Quite a number of fungi act in this way, at first producing sharply defined blotches, usually circular in outline, brown in colour and surrounded by a red margin, then finally causing perforations in the leaf. Bacteria are often found on the "shot-hole" spots, without any other fungus being present, and they are probably active agents in their production.

There are at least twenty species of fungi at present known to produce or to be associated with "shot-hole" effects in the leaves of *Prunus*, and two of these are new species determined for Victoria. The following attack the various cultivated plants as well as other species of *Prunus*:—

* 1. *Ascochyta chlorospora*, Sacc.—V.
2. *Cercospora cerasella*, Sacc.
* 3. *C. circumscissa*, Sacc.—Q.
4. *C. prunicola*, E. & E.
5. *Cladosporium carpophilum*, Thuem.—N.S.W.
* 6. *Clasterosporium amygdalearum*, Sacc.—V., S.A., N.Z.
7. *Cylindrosporium padi*, Karst. (= *Septoria cerasina*, Peck).
* 8. *Exobasidium vitis*, Prill. & Del.—V., Q.

* 9. *Gnomonia circumscissa*, McAlp.—V.
10. *Ovularia circumscissa*, Sorok.
11. *Phyllosticta circumscissa*, Cooke.
*12. *P. perforans*, Sacc. & Matt.—V.
*13. *P. persicæ*, Sacc.—V., S.A.
*14. *P. prunicola*, Sacc.—V., S.A., Q.
15. *P. serotina*, Cooke.
*16. *Puccinia pruni*, Pers.—V., N.S.W., Q., S.A., T.
*17. *Septoria amygdali*, McAlp.—V.
18. *S. effusa*, Desm.
19. *S. pruni*, Ellis.
20. *S. ravenelii*, Thuem.

Cladosporium carpophilum is usually associated with scabbing of Peaches and Plums, but in Ohio it also causes "shot-hole" in leaves of the Peach.† *Phyllosticta perforans*‡ produces circular or elliptic perforations, and *Ovularia circumscissa*§ is noted by Sorokin as producing "shot-hole" just as bad as *Cercospora circumscissa*.

Fungi producing "Shot-hole" in Australia.

Since the shot-hole appearance of the leaves of stone-fruit trees has become very common of late years, I investigated the subject at some length and examined over a thousand specimens in connection with it. The results were very remarkable, and not only were several fungi new to science discovered, but the relationships of some of the fungi already known were cleared up.

It does not necessarily follow that because a fungus is found associated with the "shot-hole" it therefore produces the disease. This can only be definitely settled by infection experiments, but in the absence of such, there are a number of fungi so constantly associated with the effects that in all probability they produce them. Of the shot-hole fungi given above, the ten marked with

† Selby, Bull. No. 92, Ohio Ag. Exp. Station, p. 231 (1898).
‡ Sacc., Syll. xiv., p. 849 (1900).
§ Sacc. Syll. xi. p. 598 (1895).

an asterisk are found in Australia, although some of them are not very common. *Cladosporium carpophilum*, which causes "freckle" in the Peach, is not known to produce "shot-hole" here as in Ohio. *Cercospora circumscissa* is only recorded on the Peach from Queensland by Massee, and *Septoria amygdali* was only found in one locality associated with "shot-hole" in Almond-leaves. *Puccinia pruni* has only been known very occasionally to produce shot-hole effects, and there remain six species of fungi which may be regarded as principally producing the disease in Australia, viz. :—

Clasterosporium amygdalearum.
Phyllosticta prunicola.
Ascochyta chlorospora.
Gnomonia circumscissa.
Exobasidium vitis.
Phyllosticta persicæ (including *P. circumscissa*).

Clasterosporium amygdalearum is essentially the shot-hole fungus of Australia, and is well fitted to survive and spread by reason of its mode of life and the different stages in its life-history which enable it to adapt itself to the various climatic conditions prevailing. It has been found in such widely separated localities as Victoria, South Australia, and New Zealand, and on Almond and Apricot, Peach and Plum trees.

It has been recorded as far back as 1883 for South Australia, and not only occurs on the leaves, but likewise on the branches and fruit of stone-fruit trees. During the growing season it produces abundant tufts of conidia, and they readily germinate if the necessary moisture is present. It can live, grow and multiply either upon fresh or dead tissue, and thus it can produce its conidia either on living portions of the tree or on dead parts separated from it.

In addition to this, it can develop a pycnidial stage in which the reproductive bodies are enclosed in a case and fitted to survive the winter.

Phyllosticta prunicola is found associated with and growing among the tufts of *C. amygdalearum* and represents a higher

stage of it. It may either succeed or accompany the latter, and occurs on all the cultivated species of *Prunus*, although *C. amygdalearum* has not as yet been found on the Cherry here. The pustules are not usually found on the leaves still borne by the tree, as the brown spots fall away and then develop the perithecia, but during wet autumns they are not at all uncommon on attached leaves. On the shrivelled rotten fruits lying on the ground the perithecia sometimes literally cover the surface.

Saccardo* suggests that the highest or ascidial stage of this fungus is *Leptosphaeria pomona*, Sacc., but I have only found *L. vagabunda*, Sacc., on dead Peach branches.

The life-history as far as definitely known at present would be represented thus:—

1. Conidial stage *(Clasterosporium)*.
2. Pycnidial stage *(Phyllosticta)*.

These stages are usually accompanied by various other fungi which act as scavengers and hasten decay.

While neither of these two stages has been found north of the Dividing Range in Victoria, their place seems to be taken by two other related fungi which produce shot-hole effects, viz., *Ascochyta chlorospora* and *Gnomonia circumscissa*.

Ascochyta chlorospora was first found on languid leaves of the Plum in Italy, but has since been met with in Victoria and South Australia, causing "shot-hole" of the Almond, Apricot, Peach and Plum. It also occurs on the withered fruit of Peach and Apricot, and although found in the neighbourhood of Melbourne, it seems more particularly adapted for the Goulburn Valley and the dry northern regions.

Gnomonia circumscissa was often found associated with the preceding, and I regard it as the ascidial stage of that fungus. It occurred on the leaves of the various cultivated species of *Prunus*, scattered promiscuously over the leaf when dead, but on definite rounded spots on the living leaf, from which the tissue

* Syll. Fung. iii. p. 5 (1884).

ultimately dropped out. I have not met with any pycnidial stage of this fungus, and the life-history stages at present known are as follows:—

1. Conidial stage *(Ascochyta)*.
2. Ascidial or highest stage *(Gnomonia)*.

In an allied species found on Cherry-leaves *(G. erythrostoma)* the pycnidial stage is referred to a species of *Septoria*.

Exobasidium vitis.—While investigating the cause of shot-hole in Apricot leaves from a dry district such as Ardmona during the month of October, it was found to be quite different from that in the neighbourhood of Melbourne. In my own garden at that season of the year there was abundance of *Clasterosporium amygdalearum* producing "shot-hole" in Apricot leaves, but that fungus has never been found in the Ardmona district. Instead of that, white patches occur on the brown spots of the leaves, and on microscopic examination these turned out to be the same as those previously found on the Vine in the same district and consisted of *Exobasidium vitis*.

This fungus has already been described for Australia in my "Additions to the Fungi on the Vine," and the disease caused by it was first observed there in February, 1895. In the interval this fungus has evidently spread from the Vine to the leaves of the Apricot, Peach and Plum, but while in the Vine leaves it causes patches to become red or brown, in the leaves of stone-fruit trees it produces actual "shot-hole."

The occurrence of this fungus in association with the shot-hole of stone-fruit trees is interesting in many ways, and adds another to the numerous fungi producing such effects.

It has been pointed out by various writers that there is some peculiarity about the leaves of stone-fruit trees which renders them liable to be affected in this way, and the present case shows that different leaves are affected by the same fungus in different ways.

Phyllosticta persicæ (including *P. circumscissa*).—In any list of "shot-hole" fungi for Australia it may seem rather strange that *Phyllosticta circumscissa* is not mentioned, which is regarded

by many as the "shot-hole" fungus *par excellence*, as if it were the only fungus capable of producing such effects, and whenever a shot-hole is met with in the leaves of stone-fruit trees it is usually attributed without any investigation to *P. circumscissa*. And yet, although I have spent over ten years in investigating the diseases of plants in Australia and examined over a thousand leaves of stone-fruit trees from various parts of Australia and New Zealand, submitting them to the most searching examination, wherever a "shot-hole" was due to a *Phyllosticta*, I have invariably found it to be *P. prunicola*, or very occasionally *P. persicæ*. *P. circumscissa* was determined by Cooke in 1883 from leaves of Apricot and Cherry sent from South Australia by the late Frazer S. Crawford, and the following brief description was given of it in *Grevillea* (Vol. xi., p. 150, June, 1883):—"On both surfaces. Spots orbicular, rufous-brown, at length falling out and leaving round holes. Perithecia few, minute, innate. Sporules elliptic. $8 \times 2\ \mu$."

Both *P. prunicola* and *P. persicæ* have been met with on Apricot-leaves from South Australia, and *P. circumscissa* approaches so closely to the latter constituted by Saccardo in 1879 from Peach-leaves, and the spores are sometimes so similar that it is highly probable they both represent the same fungus on different host-plants, and so I have included the shot-hole fungus of Cooke under the previously determined one of Saccardo. It is presumed that the spores were hyaline, and hence I have referred it rather to *P. persicæ* than to *P. prunicola*, in which the spores are clear olive.

P. persicæ has been found both in Victoria and South Australia on Apricot and Plum-leaves as well as on Peach-leaves. It is of comparatively rare occurrence, and does not seem at present of great economic importance.

Puccinia pruni.—This fungus has not hitherto been associated with "shot-hole," and since this is the first record of it, the subject may be briefly referred to. Some Almond-leaves sent from South Australia were badly riddled with "shot-hole," and also severely affected with *Puccinia pruni*. After careful

examination, it was found that the rust-fungus was responsible for the effects, although it had not been previously known to act in that way.

This fungus has become so well established in Australia, owing to the climatic conditions being peculiarly favourable to its development and spread, and its effects have become so intensified season after season, that now instead of merely causing the tissue of a leaf to become yellow in spots, it causes these spots to drop out, and the tree protects itself by limiting the area of operations as much as possible. The cumulative effects of fungi year after year may lead to startling results, and in the case of this particular rust, not only does it occur on the leaves of stone-fruit trees as in the older countries of the world and occasionally on the upper surface, but also on the branches and fruit, causing considerable damage to the latter. So the extension in spread is often accompanied by an intensity of action which is more destructive to the tissues than formerly.

Distribution of the "Shot-hole" Fungi in Australia.

I have only had an opportunity of examining specimens from certain parts of the Commonwealth, and therefore only a limited view can be taken of the distribution, but there are sufficient data to show that the nature of the climate is the great determining factor in the distribution of the species.

Around Melbourne and south of the Dividing Range in Victoria I found the prevalent forms to be *C. amygdalearum* and *P. prunicola;* but in the Goulburn Valley and the drier districts of Victoria it was *A. chlorospora* and *G. circumscissa*, together with *Exobasidium vitis*.

In South Australia, *C. amygdalearum* and *P. prunicola* were the common forms, with *P. persicæ* occasionally.

In Queensland, in the neighbourhood of Brisbane, *Cercospora circumscissa* was determined by Massee on Peach-leaves, and this is the only State in which it has been recorded. This is the great "shot-hole" fungus of California, especially in the coast regions, on account of the frequent fogs and the general humidity

of the atmosphere. *P. prunicola* and *E. vitis* also occurred in Queensland.

It is interesting to notice that *C. amygdalearum* was found in the Auckland district of New Zealand as well as in Victoria and South Australia, but *P. prunicola* has not been recorded yet, although it probably occurs there.

I am not aware of any of these "shot-hole" fungi having been definitely determined for New South Wales, although some of them are almost sure to occur there. Dr. Cobb has indeed referred to the "Shot-hole disease of the Apricot and other Stone-fruit trees" as being due to *P. circumscissa*,* but the drawing given there in illustration of his remarks only shows a Hyphomycete and probably a form of *Torula* which has nothing to do with the production of the disease.

Shot-hole effects in relation to the Host-plant.

It is a question for consideration whether such effects are due to the nature of the fungus or the nature of the host-plant, and the prevalence of shot-hole effects in the genus *Prunus* would seem to indicate that the reaction of the host-plant has a considerable influence on the result.

Tubeuf in his "Diseases of Plants induced by Cryptogamic Parasites," devotes a chapter to the reaction of host to parasitic attack, and concludes that while the reaction is fairly constant for the same host and fungus, yet different hosts behave differently in attacks of the same fungus. In the case of many leaf-spot diseases, he assumes that the mycelium excretes a ferment which causes the immediate death of any cell it may touch. The death of the cells would soon prevent the further extension of the parasitic fungus, and in this way the area of the disease would be circumscribed. Duggar† in his paper on "The shot-hole effect on the foliage of the genus *Prunus*," states his belief that from the number of species of fungi producing this effect, it

* Ag. Gaz. N.S.W. Vol. iii. p. 289 (1892).

† Proc. Soc. Prom. Agr. Sci. pp. 64-69 (1898).

was not due to any peculiarity on the part of the fungi, but to a peculiar reaction of the plant to the injuries received. Spraying experiments with chemicals such as formalin and corrosive sublimate showed that similar results followed from their use, and from these experiments and other observations the author arrived at the conclusion "that the shot-hole effect of plums, peaches, cherries, &c., is a peculiar reaction of the plant to injuries such as may be produced by many fungi, by certain chemical reagents and possibly by other causes."

It has already been shown that at least twenty different species of fungi produce shot-hole effects, and this result seems to be due to an effort on the part of the plant to throw off the irritant, whatever it may be. It is not to be inferred, however, that the spotting of the leaves can develop into "shot-hole" only in the genus *Prunus*, although it is so very marked there. I have observed the cumulative effects of a fungus (*Phyllosticta pelargonii*, n.sp.) for some years on an Ivy-leaved Pelargonium. For several years the leaves had been spotting badly, and this season actual shot-hole was produced just as bad as in the Plum or Peach-leaves.

Apple and Apricot "Shot-hole" contrasted.

The great Australian shot-hole fungus, *Phyllosticta prunicola*, attacks the Apple as well as the stone-fruit trees, and it is interesting to note the different ways in which the fungus affects the Apricot and the Apple-leaf, for instance. In the Apricot-leaf there are generally produced, as the final effects of the fungus, distinct round holes, as if small shot from a gun had passed through, and the margin of the hole is neatly and firmly rounded off by the callus or healing tissues. The wound is thus healed, the cause of the mischief is thrown off, and the injury is restricted as much as possible. In the Apple-leaf, on the other hand, there are minute round or irregular brownish spots produced, generally surrounded by the ruddy-brown margin, as in Apricot, but large surrounding portions are discoloured besides. The spot gradually becomes thinner and thinner, as if excavated from above and below, until

finally an irregular rupture takes place, and the frayed margin of decayed tissue usually remains, without any attempt at a healing process. It is on the marginal decayed tissue that the perithecia are generally produced, and soon this falls away in shreds and patches, carrying the perithecia with it. The process of healing seems to have been developed in the tissue of the leaves of stone-fruit trees, because they are so peculiarly susceptible to the fungus. While the leaves of the Apricot-tree are riddled as if with shot, the Apple-leaf is not generally much affected, and the disease is not considered serious, nor generally observed by the orchardist. There may be some peculiar delicacy and susceptibility about the genus *Prunus*, especially when grown under Australian conditions, which causes it to respond readily to any injury, independent of the particular species of fungus concerned in it. In the Apricot this particular fungus causes "brown spot" of the branches, "shot-hole" of the leaf, and "scab" of the fruit, while it is only as yet known on the leaf of the Apple, causing leaves here and there to be ruptured in spots, or large brown patches to be formed towards the centre. There is an Apple-tree growing in my garden beside an Apricot-tree, and while it is difficult to find a leaf unaffected in the latter, it requires careful searching to detect a single leaf of the Apple with the fungus upon it.

Summary.

There are at least 20 known species of fungi associated with the shot-hole of stone-fruit trees belonging to the Sphaeropsides and Hymenomycetes, with the exception of one (*Gnomonia circumscissa*), which belongs to the Pyrenomycetes, and is the higher stage of one of the imperfect fungi (*Ascochyta chlorospora*). There are at least 10 species associated with "shot-hole" in Australia, the chief of these being, as far as Victoria is concerned, *Phyllosticta prunicola* with its conidial stage *Clasterosporium amygdalearum*; and *Gnomonia circumscissa* with its conidial stage *Ascochyta chlorospora*.

The shot-hole effects in stone-fruit trees are variously explained. Tubeuf considers that the mycelium of the fungi concerned

excretes a ferment or poison, causing the death of any cell it may reach, and consequently the effects are so deadly and so circumscribed that the well-known appearance is produced. Duggar, on the other hand, is of opinion that it is not due to any peculiarity on the part of the fungi, but to some inherent property of the plant itself, whereby it has this peculiar reaction to injuries received. He called attention to the fact that nearly all injuries of stone-fruit trees take the form of shot-hole effects, but the fungi concerned in these effects were only studied to a slight extent.

My own observations generally agree with the latter, and show that the healing tissue is only formed round the spot while the leaf is alive, and that it is a protective check against injuries produced by fungi and other agents.

While *Phyllosticta prunicola* and *P. persicæ* have been found on the "shot-hole" of Apricot-leaves from South Australia, no species agreeing with *P. circumscissa* of Cooke has been determined. It might either be an immature form, or very probably *P. persicæ* determined by Saccardo in 1879 on Peach-leaves.